

Impaired contrast sensitivity in diabetic patients with and without retinopathy: a new technique for rapid assessment

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SUMMARY A simple technique is described for assessing the sensitivity of the human visual system to gratings at threshold contrast. The technique has advantages for clinical use in that it is (1) inexpensive, (2) quick to administer, (3) portable, and (4) relatively free from bias. Forty-two diabetic patients and 84 normal controls have been tested. Fifteen diabetic patients (6/20 with retinopathy and 9/22 without) had test scores more than two standard deviations below the norm for age-matched controls.

The threshold contrast at which a pattern of stripes is just visible is a measure of visual function that has recently received great attention. It differs from conventional acuity in several respects^{1–3} and can pick up deficits not detected by more conventional measures in lens^{4–5} and retinal^{6–10} pathology, glaucoma,^{11–15} retrobulbar neuritis,^{16–18} and other disorders.^{3, 19–21} The contrast threshold is best measured by electronically varying the contrast of a pattern on the surface of a cathode ray tube,^{22–24} but such a system is not convenient for widespread clinical use. Arden²⁵ has therefore devised a test consisting of gratings printed on cards. The contrast of the gratings decreases along the length of the stripes. The subject covers the grating with a card, exposing the lowest contrast first, until he reports that he can see the stripes. The test has its clinical utility^{11, 15, 25} but is expensive to produce, costing about \$200 (£135) to purchase. This method of measuring contrast is open to the objection that strategic differences in criterion may have a considerable and indeterminate influence. By cutting the Arden plates into discs Vaegan and Halliday²⁶ devised a printed contrast sensitivity test with four-alternative forced choice format, in which subjects were required to report the orientation of the stripes.

The aim of this article is to describe a simple two-alternative forced choice test which is both quick to administer and cheap to reproduce. It differs from the other tests in seeking to obtain a rapid but reliable estimate of the detectability of gratings with just one spatial frequency, namely 4 cycles/degree, the frequency at which the sensitivity of the visual system is near its maximum.²³ The orientation of the gratings is usually horizontal but can be varied if required.

Arden,²⁷ Ghafour *et al.*,⁶ Hirsch and Puklin,²⁸ and Hyvärinen *et al.*⁷ have reported that contrast sensitivity is reduced in diabetic patients. Our test was developed to investigate diabetic patients with normal Snellen acuity. All the patients received a complete ophthalmological examination on the basis of which they were divided into two groups: those with and those without retinopathy.

Details of the test

The test comprises a series of 10 pairs of square plates. The pairs are presented with one plate above the other, the grating in the top or the bottom plate at random. The observer is forced to choose whether the top or the bottom plate contains the grating, guessing if necessary. The first pair of the series has a grating with high contrast which serves as an example, and the gratings in subsequent plates

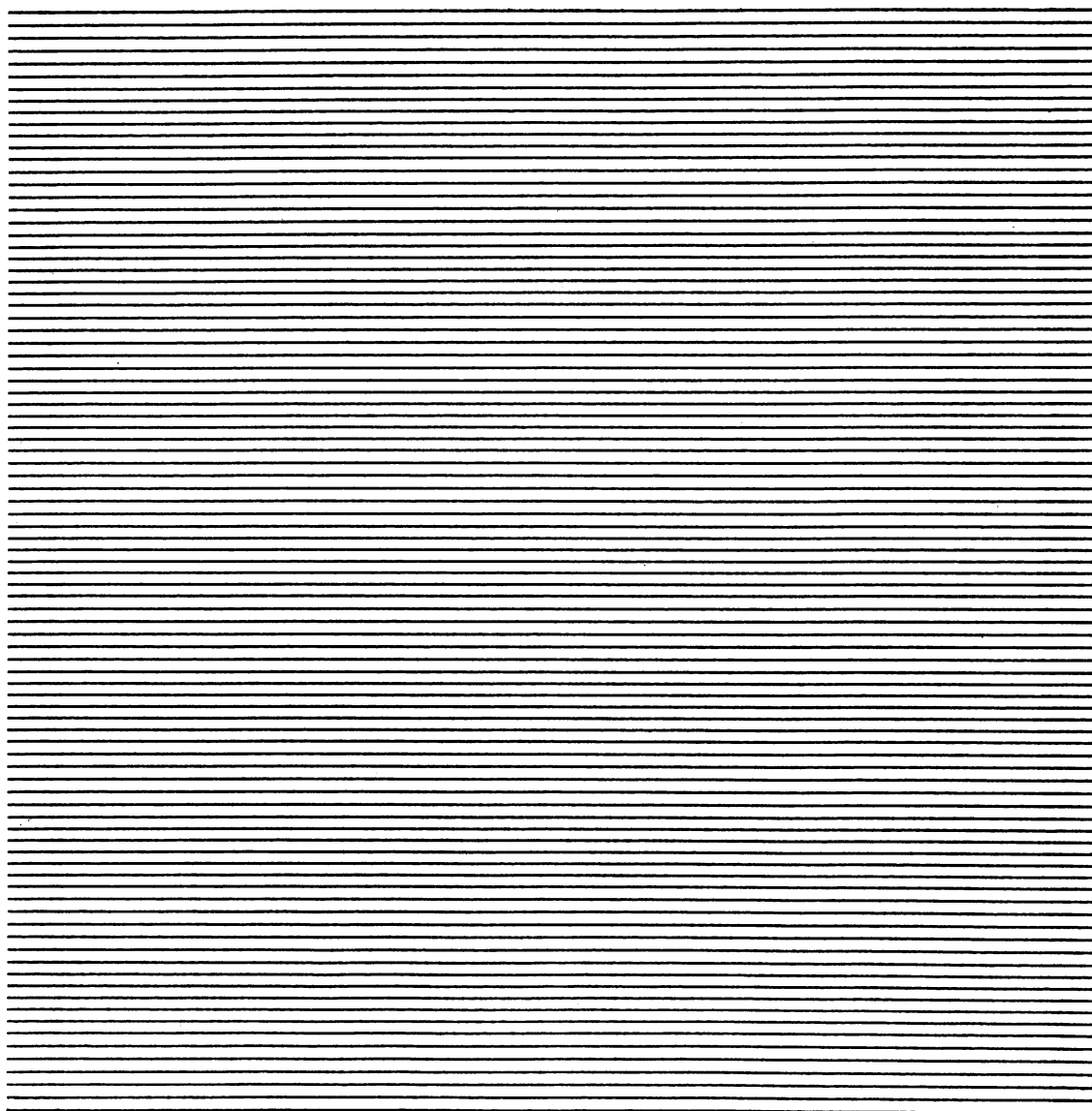


Fig. 1 An apparent grating with square-wave luminance profile resulting from variations in the spacing of the lines, suitable for viewing at 6 m.

decrease in contrast. The plates are designed to be viewed at 6 m, at which distance they subtend 2° by 2° and have a spatial frequency of 4 cycles/degree. (In the present study the plates were reduced in size by 33% by means of electrostatic photo-reduction so that they could be viewed at 5 m, the distance at which visual acuity is usually measured in Italy. They subtended $1.5^\circ \times 1.5^\circ$.)

The test plates are printed from computer-

generated plots of parallel lines that vary in their separation and thus their density, as shown in Fig. 1. They have a luminance profile that has been represented schematically in Fig. 2.

At the distance from which the plates are viewed the individual lines can no longer be seen. The variations in line density are, however, visible. These variations in density themselves comprise stripes (apparent gratings with a square-wave luminance

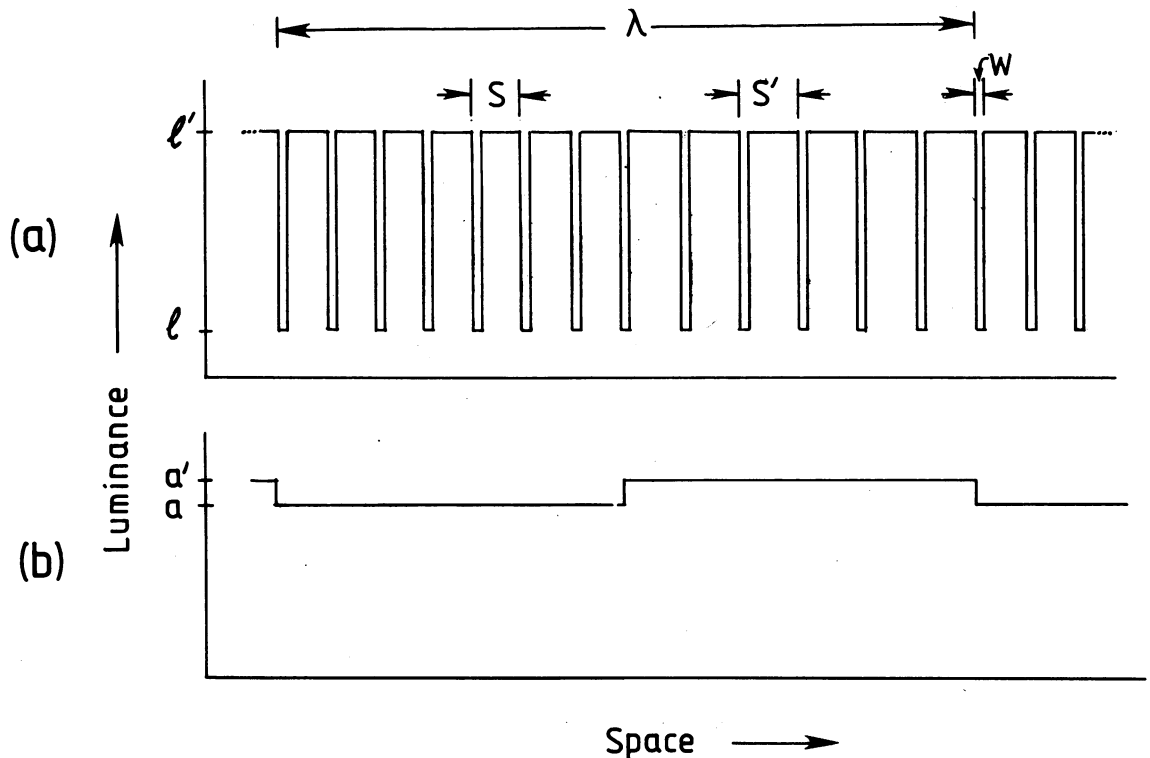


Fig. 2a Luminance profile of the grating shown in Fig. 1. The ink in which it is printed has a luminance of l , and the paper a luminance of l' . The spacing of the lines (width w) alternates between s and s' every λ units of length so as to change the line density with a square-wave luminance profile shown in Fig. 2b. When viewed from a distance at which the component lines cannot be resolved, the grating has an apparent contrast of $(a' - a)/(a' + a)$ and a spatial frequency of $1/\lambda$.

profile and a period of 36 mm—i.e., a spatial frequency of 28 cycles/m. The Michelson contrast of the apparent grating is given by the expression

$$(a' - a)/(a' + a)$$

where a and a' are the mean reflectances of the closely spaced and widely spaced lines respectively. The mean reflectance is determined by the reflectance of the paper, the reflectance of the ink, and the width and spacing of the lines. It can be shown that the above expression reduces to

$$\frac{cw(s' - s)}{(1 + c)ss' - cw(s + s')}$$

where c is the contrast of the ink on the paper, w is the width of the lines, and s' and s are the maximum and minimum separation of the lines respectively (see Fig. 2). From the above expression it can be shown that the contrast of the apparent grating will change little with changes in the contrast of the ink on the page or the width of the individual lines, factors that

might be expected to vary with printing impression. For values of the parameters within the range used, changes of 10% in the width of the lines or the contrast of the ink on the page change the contrast of the apparent grating by a similar amount. Contrast sensitivity in normal persons may vary by a factor of 2 or more, for example, between 0.5% and 1%. If an apparent grating is made with a contrast of 0.5%, and the line width or contrast of the ink alters by, say, 20% (which is more than would occur in practice), then the contrast of the apparent grating would be expected to vary between 0.4% and 0.6%, depending on the direction of variation in these parameters and the extent to which they covaried. The changes in apparent contrast from one printing impression to another are therefore likely to have little effect on the percentile scores obtained by the test and thus on its ability to discriminate normal from abnormal vision. The contrast of the apparent grating is critically determined by the separation of successive lines, and this should vary little with printing impression.

As mentioned above, the test plates were reduced for use at 5 m. The line separations are shown after

Table 1 *Reduced version of low contrast plates for use at 5 m*

Plate pair	Separation (mm)*		Nominal contrast (%)
	Maximum	Minimum	
1	1.57	1.33	2.07
2	1.51	1.33	1.62
3	1.45	1.33	1.13
4	1.43	1.33	0.96
5	1.40	1.33	0.69
6	1.39	1.33	0.59
7	1.37	1.33	0.40
8	1.36	1.33	0.30
9	1.35	1.33	0.20
Blank	1.33	1.33	0.00

*Values calculated on the basis of the photoreduction.

reduction in Table 1, together with a nominal value for the contrast of the apparent grating based on a value of 0.7 for the contrast of the ink on the paper and a value of 0.35 mm for the width of the lines. The separation of lines was chosen so that the apparent contrast of successive gratings decreased with intervals on a logarithmic scale that were as evenly spaced as the technical constraints would allow. (In the light of experience with the test a revised version has now been produced for use at 6 m, and the details of this test are shown in Table 2.)

The contrast of the apparent grating was measured for the photocopies of the first two test plates by means of a bifurcated optic fibre to project light to, and collect light from, a rectangular portion of the plate measuring 10×70 mm, orientated with the long axis parallel to the lines. The contrasts of the first two plates were within 0.2 of the values tabulated. The nominal values of contrast may therefore be taken to be reasonable estimates of the actual values.

Subjects and methods

Forty-two diabetic patients, 22 male and 20 female, aged 12–75 and 84 normal volunteers, 52 male and 32 female, aged 14–68 took part in the study. All subjects (patients and volunteers) were selected as having a Snellen acuity of 1.0 or more (5/5 as it is usually measured in Italy), after correction where necessary (no subject was amblyopic). The diabetic patients were chosen from those patients who regularly attended the eye clinic at L Sacco Hospital, University of Milan. Hospital staff, medical students, and patients' relatives volunteered to act as unpaid (age matched) control subjects.

All subjects underwent a full ophthalmological investigation which included Snellen acuity, slit-lamp examination, tonometry, and direct and indirect ophthalmoscopy. The patients were also examined

Table 2 *Revised version of low contrast plates for use at 6 m*

Plate pair	Separation (mm)		Nominal contrast (%)
	Maximum	Minimum	
1	2.22	1.38	4.76
2	2.06	1.54	2.82
3	1.96	1.64	1.71
4	1.90	1.70	1.06
5	1.86	1.74	0.64
6	1.84	1.76	0.42
7	1.82	1.78	0.21
Blank	1.80	1.80	0.00

by Goldmann lens biomicroscopy and fluorescein angiography. In none of the subjects who were admitted to the study could we detect any ocular alteration such as glaucoma, cataract, or minimal opacities, although 34 normals and 24 patients needed optical correction.

Twenty-two patients (11 male and 11 female aged 17–72, mean 46) had no detectable retinopathy. Fluorescein angiography showed no evidence of microaneurysms, haemorrhages, soft or hard exudates, areas of capillary non-perfusion, or leakage of vessels at the posterior pole or in the periphery of either eye. The length of the patients' illness ranged from 1 to 22 years (mean 7 years). Eight were affected by type I diabetes mellitus and 14 by type II.²⁹

Twenty patients (11 male and 9 female, aged 16–75, mean 42) had retinopathy. Nineteen had a background retinopathy (microaneurysms, scattered haemorrhages, and a few hard exudates at the posterior pole) and one, a male aged 48, had proliferative retinopathy with an initial peripheral neovascularisation. In all but one, a 17-year-old female, the retinopathy was bilateral. In three there was an initial macular oedema with retention of good visual acuity. Two other patients presented areas of capillary non-perfusion at the periphery of the fundus. The contrast test was administered prior to argon laser photocoagulation when this was required. The length of the patients' illness ranged from 3 to 31 years (mean 15 years). Twelve patients were affected by type I and eight by type II diabetes.

The test plates were mounted on the pages of a spiral bound book. The book was fixed on a wooden stand at a viewing distance of 5 m and illuminated by a filament lamp (60 watts at a distance of 1.5 m) so that the mean luminance was about 50 cd/m². Care was taken to ensure that the position of the lamp, plates, and eye of the observer did not vary from one test to the next. The series of plates was presented three times. Eyes were tested in random order.

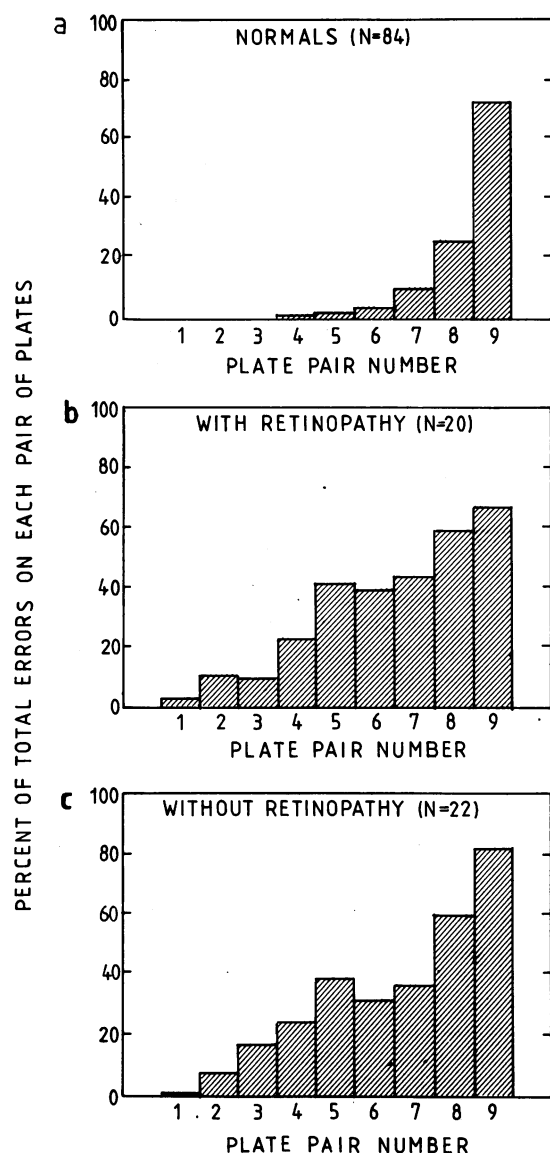


Fig. 3 Histogram of the number of errors made on stimulus pairs 1-9, for (a) normal control subjects, (b) diabetic patients with and (c) without retinopathy.

The data for control subjects and patients were collected over the same period of time (about one year), and so any degradation of the plates that may have occurred could not have accounted for the differences between groups.

Results

In Fig. 3 the errors made by each group of subjects

are shown separately for the nine pairs of test plates. From these histograms it is evident that on the pair of plates with the lowest contrast stimulus (pair number 9), subjects were not responding to the grating but to some aspect of the blank stimulus that resembled a grating (see Details of test). Were subjects responding at random, that is, appropriately for a grating they could not see; an error rate of about 50% would have been expected. Both normal subjects and patient groups responded with an overall error rate of about 75%, a rate significantly above chance. The responses to this pair of stimuli have been included in the analyses that follow because when they were removed the findings were not appreciably changed.

An initial set of analyses was performed on the total number of errors made by the two eyes on the three presentations of the test. Preliminary analyses of the data for normal subjects failed to reveal any sex differences but indicated an increase in errors with age, maximal over the age of 50. On the basis of these analyses the normal subjects were divided into three groups: 40 young (14-29, mean 22); 30 middle-aged (31-48, mean 40); 14 older (50-68, mean 59). The total error scores for both eyes averaged: 5.2 (SD 2.5), 7.3 (SD 5.2), and 11.0 (SD 7.6) for the three age groups respectively. On the basis that the percentage correct responses to plates 7 and 8 were respectively slightly more and slightly less than 75%, the mean contrast sensitivity (reciprocal of contrast threshold) for the group was between 250 and 330. For the patients the total error scores were converted to z scores by comparison with the appropriate age matched control group. Six of the 20 patients with retinopathy and nine of the 22 without had total error scores more than 2 standard deviations above the mean for the normals (see Table 3). There were no differences between the error scores for patients with type I and type II diabetes or those with and without retinopathy. The lower proportion of older patients with poor z scores is presumably because of the

Table 3 Number of patients in each age group (size n) with and without retinopathy, whose error scores were more than 2 standard deviations above the mean for age matched controls. The scores were calculated on the basis of the total errors for both eyes on all trials, total errors for the worst eye on all trials, and errors for both eyes on the first trial only

Age range	With retinopathy			Without retinopathy			n
	Total	Worst	First	Total	Worst	First	
10-29	1	1	1	2	5	5	7
30-49	4	4	4	6	3	4	5
50+	1	1	2	12	1	1	10
Total	6	6	7	20	9	10	22

greater variability between normal individuals in the older age group.

Similar analyses were also performed using the scores for the eye with the highest error score, and these produced closely comparable results (see Table 3).

In both of these analyses the correlation between the number of errors and the length of the disease was positive (Spearman rank correlation between 0.2 and 0.3) but did not approach significance, regardless of the presence or absence of retinopathy.

When the error scores for the two eyes on the first presentation of the test were considered separately, they were highly correlated with the total errors on all presentations (normals: $r_s 0.85$; patients: $r_s 0.93$). As can be seen from a comparison of the data in Table 3, a single presentation of the test to each eye (taking about one minute per eye) would have been sufficient to have detected all but one of the nine patients without retinopathy who had an impaired contrast sensitivity.

Discussion

All the patients had a Snellen acuity of 5/5 or better, corrected if necessary. Nevertheless, nine of the 22 without retinopathy and six of the 20 with retinopathy had contrast test scores more than 2 standard deviations below the norm. No comparable figures are available from previous studies, although Ghafour *et al.*⁶ report a significant difference between normals and diabetic patients without retinopathy as well as those with. In neither the present study nor those previous to it was impairment in contrast sensitivity^{6, 28} or other visual function³⁰ related to observable retinal pathology (except when the pathology was gross⁷), possibly because the retinopathy is often very localised. The test we have described measures visual function within the central 1.5° of the visual field. If impaired function precedes clinically evident anatomical changes, it is likely that those patients whose contrast sensitivity was impaired may later show background retinopathy.

Despite its simplicity and the speed with which it could be administered our test was sensitive enough to show the expected decline in sensitivity with age³¹⁻³⁵ and to reveal an impaired sensitivity in certain diabetic patients.^{6, 7, 28} There is a high test-retest reliability, perhaps because the forced choice procedure reduced variation due to changes in the subjects' strategy and criterion.^{26, 32, 36} The test is inexpensive, portable, and easy to score, and it can examine contrast sensitivity in any orientational meridian. Although it can measure contrast threshold at only one spatial frequency, the frequency chosen is that at which the visual system is

most sensitive²³ and which has been shown to discriminate diabetic patients from normal subjects.⁶ The test is designed to be administered only to patients who have normal Snellen acuity, but this restriction is less of a disadvantage than it might seem, given that the test is useful in detecting deficits that are not measurable by other clinical methods.³⁷

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NOTE. A new version of the test, using letters, is currently in preparation in collaboration with Dr J G Robson. Copies of this test, and of the test described here, can be obtained for a nominal charge by writing to the last-named author.

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